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ABSTRACT

A series of graphically-oriented computer-assisted instructional (CAI) lessons in elementary beam theory has been developed for an undergraduate course in solid mechanics. The lessons were implemented on the PLATO CAI system at the University of Illinois; the system included a graphical display unit (CRT) and a CDC 1604 computer. The first phase of the lessons was devoted to the presentation of theoretical derivations via a linear program; following this, the students were exposed to programs which drilled them to develop two basic skills for beam stress analysis. These were: 1) the calculation of section properties, and 2) the calculation of internal forces. Students were then given a free-flowing synthesis program which required them to input a beam idealization along with material and cross section dimensions and to produce an acceptable design. Preliminary evaluation of test results indicated that students who used the CAI programs performed slightly better than comparable students who were taught by the lecture method, and that the CAI group took less time to learn the material. The data thus indicated definite promise for increasing learning and decreasing time to criterion through the use of CAI. (PB)

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INTERACTIVE LESSONS FOR ENGINEERING--AN EXAMPLE FROM ELEMENTARY BEAM THEORY

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The concept of using interactive (on-line) computer system for instruction has been with use for some time. Unfortunately a combination of high costs and limited equipment have restricted the useful applications of these systems. New technological advances and improved computer systems are beginning to make this concept more feasible on a widespread basis. Probably the greatest single deterrent to developing engineering material for on-line systems has been the lack of availability of an inexpensive, easily programmed graphical display unit. Such systems are beginning to appear in limited situations and it is not unreasonable to anticipate that the near future (5-10 years) will see a widespread availability of this type of facility. The PLATO system at The University of Illinois [1] is an example of an easily programmed on-line graphical display system.

If we can anticipate the availability of relatively inexpensive on-line graphical terminals in the near future, the problem of generating effective engineering lessons becomes immediate. This paper attempts to look at one such attempt. Initially some of the basic concepts are discussed, then several of the programs are described in detail, and finally the results of class experience are presented. The programs have been developed on the PLATO III system at the University of Illinois. The system includes a graphical display unit (CRT) with slide display capabilities. Up to 20 student stations can be handled simultaneously by a CDC 1604 computer. It is felt that, while the programs are specifically written for the PLATO system, the concepts are adaptable to any system with similar capabilities.

Basic Concepts

Before discussing the lesson content, it is first necessary to determine some of the basic parameters of a typical engineering course. It is possible to cast most of the course aims in the following form:

1. Knowledge of the theory, so that limitations and assumptions are well understood.
2. Ability to analyze a problem once it has been stated.
3. Ability to formulate a problem and synthesize a solution.
4. Ability to extend and modify the basic theory to new situations.

It is possible to lump these goals under the headings of Theory, Analysis, and Synthesis.

The common way of presenting this material is in a lecture-discussion format. The shortcomings of this approach are well appreciated, and the promise of computer based education as an alternative is equally well known [1]. The body of this paper is concerned with the series of computer based education (CBE) programs which have been developed for the study of elementary one-dimensional beam theory. Before discussing these programs, I would like to briefly describe the specific advantages that each segment offers.

Theory.--When theoretical considerations or derivations are presented in lecture, they are all too often merely transferred from the teacher's notes to the student's notes. Very rarely do the students actively participate in the derivations or consider them in out-of-class study. On the computer, however, each student can actively participate in the derivation. He can see how assumptions allow him to make certain calculations and why a certain order must be followed. Obviously, students will reach different levels of understanding, but any participation in the derivation will be superior to the lecture approach.

Analysis.--The basic approach to analysis is drill and practice. The instant feedback and error analysis available from the computer are far superior to the typical lockstep and slow feedback available in lecture and discussion.

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Synthesis.--Problems of design and synthesis are almost uniformly neglected in lecture-discussion courses, usually because of insufficient time for (a) the students to investigate alternative solutions or (b) the instructors to evaluate the design. Typically, the design aspects are relegated to a senior level design project or course. The result is that for several years the student is trained in analysis, and the process of restructuring his thinking to handle synthesis problems is often traumatic. It would be much more desirable to make synthesis an integral part of each course, where it is appropriate. With the computer doing the repetitious calculations for the student and analyzing the student's design for the instructor, this approach becomes entirely feasible.

To implement these concepts, a series of lessons in elementary beam theory have been developed for use in an undergraduate course in solid mechanics. With the exception of a certain amount of introductory material and material that did not lend itself to computer presentation (approx. 2-3 hours), the lessons cover all class and homework material for elementary one-dimensional static stress analysis of beams (excluding shear stresses).

Description Of Lessons

Theory

A basic flow diagram of concepts involved in the theory lesson is shown in Figure 1. The student is initially allowed several choices of how he wishes to study the material. Two of the choices involve the methods used to derive the analysis formulas. As in many situations, there are alternative methods of derivation starting from different points of view. In a typical lecture situation, only one of these is usually presented, although it is clear that individual students may be more receptive to alternative presentations.

The third alternative is to merely have the formulas and assumptions presented with no derivation. Obviously this is not the path that we would like most students to take, but we know that there are some students who have no need or desire for the more detailed knowledge of the derivations. Note, however, that the student is forced to apply these formulas to a simple example before he is allowed to proceed.

The more detailed derivations follow a predetermined path. The student is asked to make some initial assumptions (intuitive approach) or to reach the conclusion by a geometric argument (mathematical approach). Once these initial steps have been made, the derivations are identical in form although different in mathematical detail. Typical of these steps is that shown in Figure 2. The student has determined the form for the normal stress t_{xx} and is now asked to write the equilibrium equation in the x direction.

For a number of reasons, the linear form of the program was chosen over a more free-flowing form in which the student must decide which steps to do. This was the first program the students would use and it was felt that a more structured program would better introduce them to the machine. Also, this is an introductory course and it was felt that the students might not have sufficient background to profit from a more free-flowing program. Finally, some experiences with the free-flowing program have produced mixed results [2].

Some additional features of the program are worth mentioning. For each question, the student has available two levels of assistance. By pressing one key, he will be given some fairly specific hints on how to work the problem. By pressing another key he will be shown the answer. When he has finsihed the derivation, he is told that if he has used these options so frequently, he probably should redo the derivation. The option to do so is up to the student. It is strongly felt that at this level the motivation to learn the material must come from the student, rather than being forced by the machine. In the theory section in particular, it is felt that any thought on the steps of the derivation is superior to the typical lecture approach.

Finally, the student is often unsure of the path through a derivation. The problem is heightened by a CBE system such as PLATO which has no hard copy and a transient display. Thus a simple flow chart is provided which outlines the steps. The student is shown the chart prior to starting the derivation. At any subsequent point he may return to the chart and an arrow shows him where he is in the derivation (see Figure 3).

Analysis

Two basic skills are required for beam-stress analysis:

1) Calculation of section properties (centroid and second moment of Area),

2) Calculation of Internal forces (Shear and Moment).

Programs were written to drill the students in these areas.

Section properties.--The student must calculate the centroid and moment of inertia about an axis through the centroid of three typical cross sections. Literal values rather than numerical values were eventually used due to extensive time losses in numerical calculations from student error. The literal answers are judged on a term-by-term basis and incorrect terms are underlined. The program discriminates among the alternative solutions by comparing them to the student's answer on a term-by-term basis. The available solution, which matches the highest percentage of student terms, is presumed to be the approach the student attempted to use. If terms are omitted by a student response, an appropriate message is given (Figure 4).

Shear (V) and bending moment (M).-- student must find V and M as a function of longitudinal coordinates for a series of beams (6 at present). He is led through the construction of each appropriate free body. The program will handle any statically determinate beam with point loads and uniformly distributed loads. Provision is made for the student to input and see the results of his own problem if he desires.

Synthesis

The synthesis program is a very free-flowing program. The student has a number of options available. He must input a beam idealization of his problem along with a material and cross section dimensions. In addition, information on material properties and simple section properties is available. Also, the full capabilities of the beam analysis program for shear and moment are available, which include provisions for seeing the answer. At present the program does not consider deformation or shear stresses and the problems are assigned by the instructor, although they could be stored in the machine.

Once the student has determined the maximum bending moment, he must pick a material and a cross section shape and dimensions. At present six cross sections (rectangle, T, I, tube, channel, and box) are available. In general, any dimensions are acceptable. The centroid, area, and moment of inertia for the chosen section are computed and displayed for the student. When the student feels he has an acceptable design he may request manufacture and test of his design. The test procedure checks the maximum stress with the allowable stress and computes a margin of safety. If the margin of safety is less than one the analysis stops and the student must try again. If greater than one, it is compared with the safety factor chosen by the student. If the margin of safety greatly exceeds the safety factor the student must again choose a new design. If both these criteria are satisfied, the student's design is compared with an efficient cross section (an I section actually) on an area basis. If the student's area exceeds the computer generated section area by over 10%, the student is told that a more efficient design is possible and he is encouraged to improve the design. A set of suggestions is available to aid him.

On an early test of the program it was found that students used the test portion of the program as a design aid in that they manipulated the section dimensions based on the percentages by which they were missing the efficient section rather than looking at the section modulus, $\frac{y_{max}}{I}$. To discourage this, the grade on the problem is now calculated by the formula

$$\text{Grade} = 102 - 2 \text{ (number of tests used)}.$$

Using this approach grades about 96 were not uncommon.

Student Results

During the fall semester, 1972, a section of an introductory course in solid mechanics was taught using the previously described material. In this course the beam theory section occupies the last third of the course following an introduction to the theory of elasticity and torsional analysis. The class of 20 students was split into two groups of 10. One group

followed the lecture discussion format and the second group used the PLATO format. The groups were split on the basis of the first hour exam so that each group had roughly equal numbers of good, average, and poor students.

Each group received essentially the same material and were assigned identical problems. At the end of the PLATO material (approximately 2 1/2 weeks of class time) a test was administered to both groups. This test was basically the same type of test that would be administered to a typical lecture discussion class, so little emphasis was placed on theoretical considerations. In addition each student was asked to report the time he spent out of class on the material. This information was collected at each class meeting. Anonymity was maintained by having each student devise a code word known only to himself. This of course made it impossible to correlate the homework, PLATO timings, and test scores with out-of-class time, therefore all timings must be presented as averages.

The results of these studies are shown in Tables 1 and 2. The test results indicate that the PLATO group performed slightly better on the test, even though the lecture group did better on the first two hour exams (no PLATO material). The increase in performance in the PLATO group is primarily due to the improvement of the poor and average groups. This leads one to suspect that the primary effect is due to the feedback effects and the precision required by the computer.

The results of the timing studies do not indicate significant differences in the overall time spent, but do indicate the computer approach was most time-effective in the design problem and possibly in studying for the exam. The effectiveness of the design program was primarily due to the instant availability of the analysis results (moment of inertia, centroid, area, moment, shear), so the student could concentrate on developing an efficient cross section for the structure.

The analysis and theory sections proved to be the least time-effective. However, it is felt that additional improvements particularly in the analysis section can be made to increase their effectiveness. In particular, certain input patterns must be used in the V and M programs which cause some initial difficulties. If these patterns can be simplified significant improvements should result.

Finally, although these data are obviously preliminary, they do indicate definite promise for both increasing learning and decreasing the amount of time spent on certain student activities. They very strongly indicate the feasibility of the design segment of the material.

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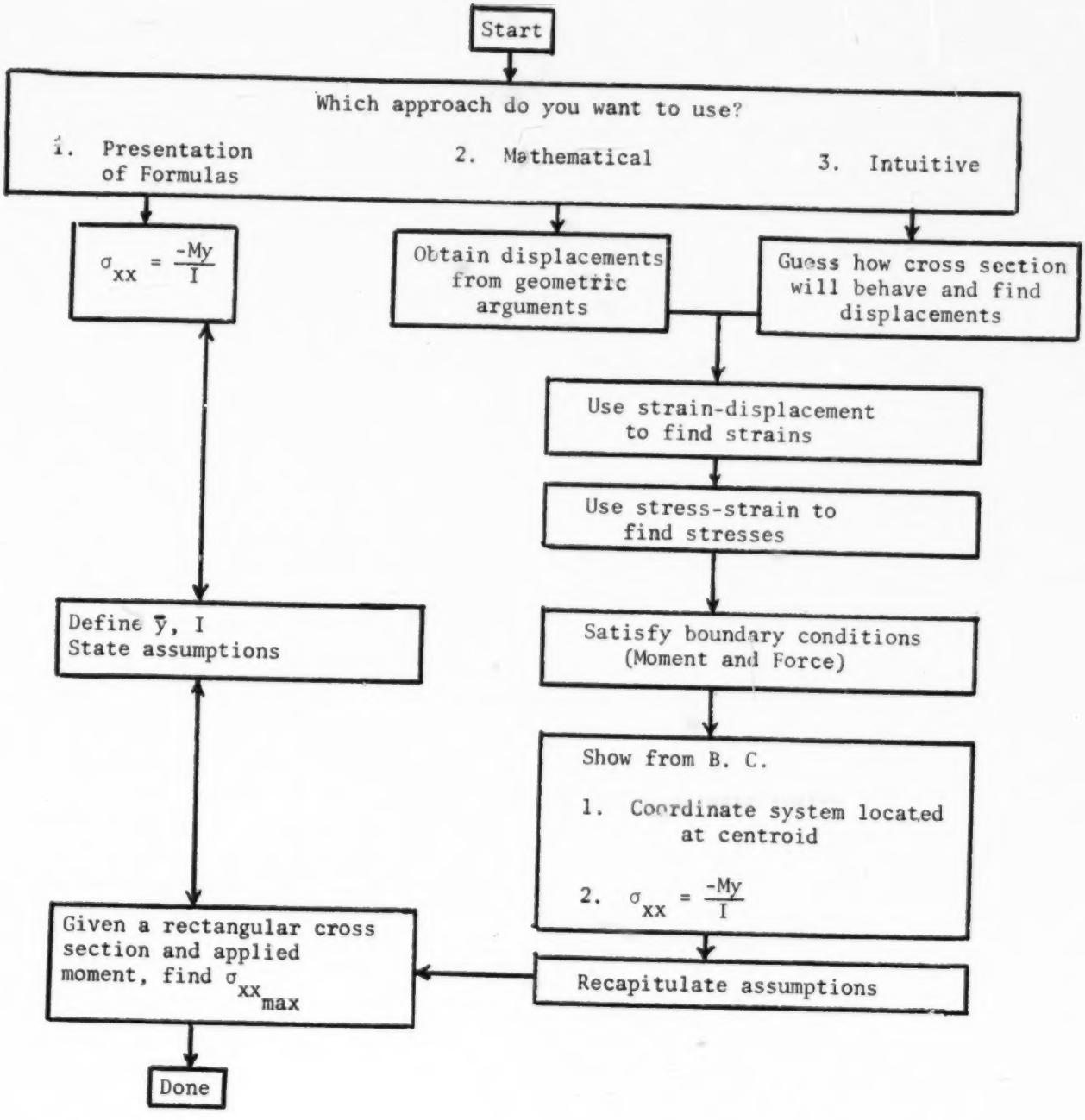
Start
Which approach do you want to use?
1. Presentation of Formulas
2. Mathematical
3. Intuitive
$\sigma_{xx} = \frac{-My}{I}$
Obtain displacements from geometric arguments
Guess how cross section will behave and find displacements
Use strain-displacement to find strains
Use stress-strain to find stresses
Define $\bar{y}$, I
State assumptions
Satisfy boundary conditions (Moment and Force)
Show from B. C.
1. Coordinate system located at centroid
2. $\sigma_{xx} = \frac{-My}{I}$
Given a rectangular cross section and applied moment, find $\sigma_{xx_{max}}$
Recapitulate assumptions
Done

Figure 1. Beam Theory Flow Chart

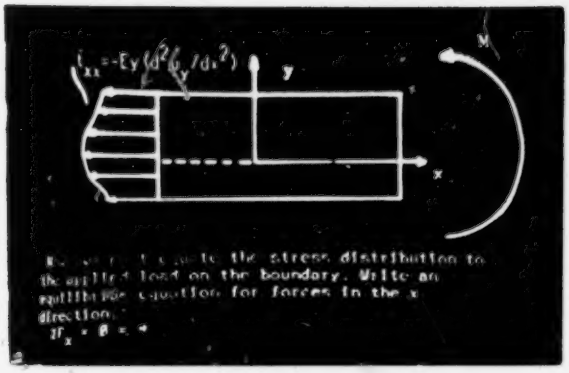

Figure 2. Beam Theory Lesson: Force Boundary Condition

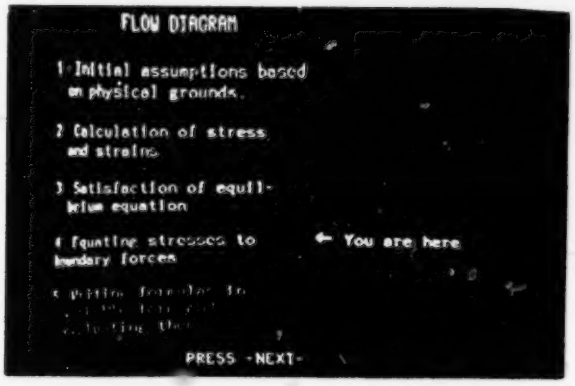

Figure 3. Beam Theory Lesson: Flow Chart

Figure 4. Section Properties Lesson: Incorrect Answer Judging

TABLE 1

Time Spent (hours)

	Analysis	Design	Exam Preparation	Total
PLATO Section	5.9[1]	3.3[1]	1.7	22.5[3]
Lecture Section	5.1[2]	4.9[2]	3.7[4]	24.3[3]

1. PLATO time only
2. Exclusive of lecture
3. Total time, including lecture
4. Includes some time spent on design

TABLE 2

	Test Results		Beam Theory Exam	
	1st hour exam[1]	2nd hour exam[1]	Objective[2]	Subjective[3]
PLATO Section	75.0%	73.9%	64%	76.0%
Lecture Section	76.5%	84.7%	52.5%	66.2%

1. Both sections in lecture discussion
2. Questions graded right or wrong
3. Graded in same fashion as first two hour exams, i.e. partial credit.